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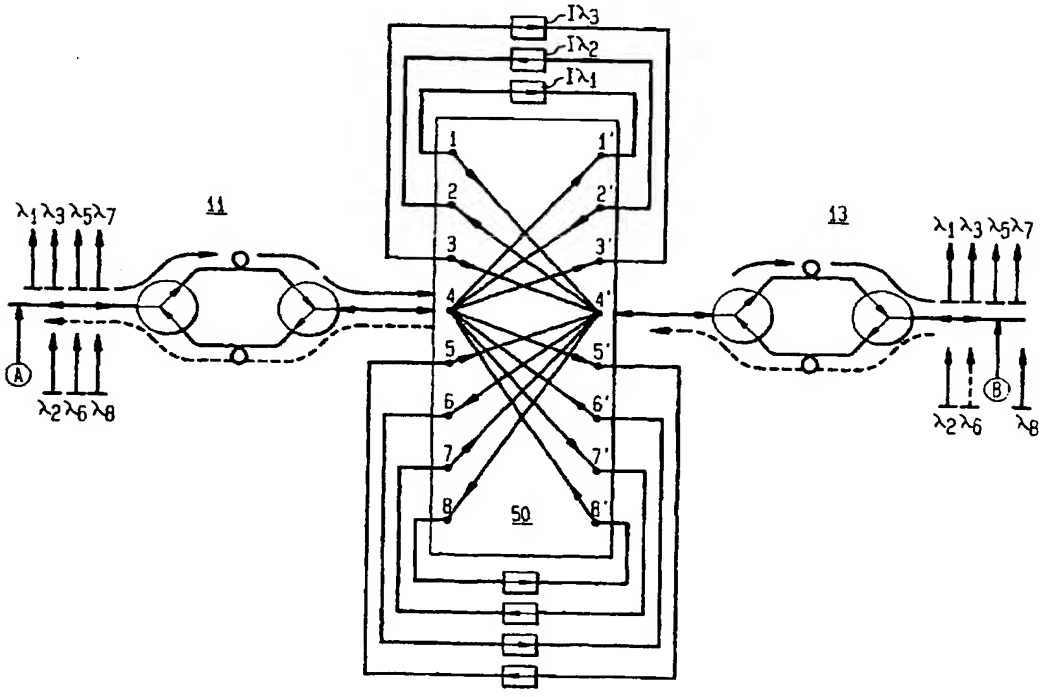
(54) **Optical amplifier for bidirectional WDM optical communications systems**

(57) In accordance with the invention, an amplifier for a bi-directional WDM optical system comprises an arrangement of multiplexers with unidirectional arms disposed between a pair of bi-directional amplification stages. The multiplexer arrangement combines and separates wavelengths in both directions and reduces the effects of Rayleigh backscattering and amplified spontaneous emission.

FIG. 5



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Description

Technical Field

[0001] This invention relates to optical amplifiers and, in particular, to an optical amplifier especially useful for bi-directional wavelength division multiplexed optical communications systems.

Background Of The Invention

[0002] Optical communications systems employing optical fibers have reached a state of technical sophistication and increasing commercial importance. Such systems have greatly increased the capacity of present and contemplated telecommunications systems. Nonetheless there is a relentless demand for ever increasing capacity.

[0003] Wavelength division multiplexed systems (WDM systems) offer the prospect of greatly increased capacity, and bi-directional WDM systems offer more efficient use of optical fiber networks and higher transmission capacity than unidirectional systems.

[0004] Amplifiers are particularly important in bi-directional optical communications systems. In such systems, signal crosstalk due to Rayleigh backscattering can degrade transmission performance. And in some systems using rare earth doped amplifiers, amplified spontaneous emission (ASE) can degrade both upstream and downstream sensitivities. As a consequence, amplifier design has assumed increasing importance in bi-directional systems.

[0005] A variety of amplifier designs have been proposed for bi-directional optical communications systems. See, for example, J-M. Delavaux *et al.*, "Repeated Bi-directional 10 Gb/s-240 km Fiber Transmission Experiment", Optical Fiber Technology 2, IEEE Photon Tech. Lett., pp. 1256-59 (1996); Shien-Kuei Liaw *et al.*, "Amplified Multichannel Bi-directional Transmission Using a WDM MUX/DMUX Pair for Narrowband Filtering", Electronic Letters (Victoria, B.C., July 1997); Ken-ichi Suzuki *et al.*, "Bi-directional Ten-Channel 2.5 Gbit/s WDM Transmission...", OAA 97, PD 12-1 ( ) and Chang-Hee Lee *et al.*, "Bi-directional Transmission of 80 Gb/s...WDM Signal Over 100 km Dispersion", OECC 97 (Seoul Korea, 1997). While amplifier designs are well developed for single channel systems, designs for WDM systems continue to have a number of shortcomings. Accordingly there is a need for an improved amplifier for bi-directional WDM optical communications systems.

Summary Of The Invention

[0006] In accordance with the invention, an amplifier for a bi-directional WDM optical system comprises an arrangement of multiplexers with unidirectional arms disposed between a pair of bi-directional amplification stages. The multiplexer arrangement combines and separates wavelengths in both directions and reduces the effects of Rayleigh backscattering and amplified spontaneous emission.

Brief Description Of The Drawings

[0007] The advantages, nature and various additional features of the invention will appear more fully upon consideration of the illustrative embodiments now to be described in detail in connection with the accompanying drawings. In the drawings:

Fig. 1 is a schematic representation of an optical amplifier in accordance with the invention.

Fig. 2 is an alternative embodiment using circulators rather than isolators between the WDMs; and

Fig 3 is alternative embodiments using 3dB couplers in lieu of one or more circulators,

Fig 4 is an alternative embodiment using plural pairs of WDMs; and

Fig. 5 is an alternative embodiment using an arrayed waveguide grating multiplexer

[0008] It is to be understood that these drawings are for purposes of illustrating the concepts of the invention and are not to scale.

Detailed Description

[0009] Referring to the drawings, Fig. 1 is a schematic representation of an optical amplifier 10 comprising a pair of amplifier sections 11, 13 with a multiplexer section 12 disposed between the amplifier sections.

[0010] Amplifier section 11 is a bi-directional amplifier preferably comprising a pair of optical circulators 14, 15 connected by a pair of fiber amplifiers 16, 17. Specifically each circulator can have three ports designated A, B, C. If we take port A of circulator 14 as the input port and port A of circulator 15 as the output port, then amplifying fiber 16, connecting port B of circulator 14 with port B of circulator 15 amplifies the signal propagating from left to right. Amplifying fiber 17 connecting ports C of circulators 14, 15 amplifies the signal right to left. Amplifier section 13 can be a bi-directional amplifier of similar structure with circulators 14', 15' and fiber amplifiers 16', 17'.

[0011] While bidirectional amplifiers employing circulators are preferred, both circulators can be replaced by two openended amplifying sections that would amplify the two sets of counter-propagating wavelengths. The disadvantage would be a noisier amplifier, more prone to lasing.

[0012] The multiplexer section 12 is an arrangement of multiplexers to separate and combine wavelengths

traveling in each direction. It preferably comprises a pair of wavelength division multiplexers (WDMs) 18, 19. The WDMs are connected by unidirectional arms $\lambda_1, \lambda_2,...\lambda_4$ containing isolators $I_{\lambda1}, I_{\lambda2},...,I_{\lambda4}$ oriented in the direction of intended propagation (as indicated by the direction of the arrows).

[0013] Switchable or latchable isolators can be used instead of fixed isolators. This would permit all or some of the channels to propagate in the same direction. Thus the propagating wavelengths can be dynamically programmed, providing greater flexibility.

[0014] In operation, signal components, traveling from left to right e.g. λ_3, λ_4 enter amplifier section 11 at circulator 14, are amplified by fiber amplifier 16 and leave via circulator 15. At WDM 18 the components are separated onto unidirectional arms designated λ_3, λ_4 respectively, and recombined at WDM 19 for entry into the second amplifier section 12. By unidirectional arms is meant optical paths containing unidirectional components, here isolators, that permit light to pass in one direction but not the other. The recombined signal enters 12 via circulator 15', is amplified in fiber amplifiers 16' and exits via circulator 14'. Signal components, traveling from right to left e.g. λ_1, λ_2 follow similar paths through amplifier 171 in the reverse direction.

[0015] A first advantage of this device is that any amplified Rayleigh backscattered signal will be blocked by the isolators in the MUX section 12. The isolators, $I_{\lambda1}$, $I_{\lambda2}$,..., $I_{\lambda4}$ can be switchable isolators, in which case, one may choose which channels propagate in which direction.

[0016] Fig 2. Illustrates an alternative embodiment wherein multiport circulators $C_{\lambda1}$, $C_{\lambda2}$,..., $C_{\lambda4}$ are substituted for isolators $I_{\lambda1}$, $I_{\lambda2}$..., respectively. The advantage of using circulators rather than isolators is that circulators provide points for adding and dropping channels. In the specific embodiment illustrated, upstream channels λ_1, λ_2, λ_3, λ_4 are separated by WDM 19. Here we use the wavelength periodicity of the free spectral range (FSR) of WDM routers, in particular the phaser type gratings, to permit addition and dropping of channels. λ_2 and λ_4 are transmitted through the circulators while λ_1 and λ_3 are dropped. In the downstream direction λ_6 and λ_8 are transmitted and λ_5 and λ_7 are added through their respective circulators $C_{\lambda5}$, $C_{\lambda7}$. If switchable circulators are used, then one may control which channels are added, dropped or transmitted, and all or some of the channels may be directed in one direction only..

[0017] Fig. 3 illustrates an alternative embodiment similar to that of Fig. 1 wherein 3dB couplers 30, 30' are substituted for circulators 15, 15' in the amplifier sections. The fourth ports of one or more couplers can be used to launch power, as from pump resources C, D to pump the fiber amplifiers. The main advantage of this arrangement is a reduction in cost by reduction in the number of circulators.

[0018] Fig. 4 illustrates another alternative embodiment using a pair of 3dB couplers 40, 40' and a MUX section comprising a plurality of pairs of WDMS. In this arrangement WDMs 18, 19 correspond to a specific band while WDMs 48, 49 correspond to a different band shifted wavelength. In this arrangement a larger number of channels can be accommodated for the same interstage loss. Alternatively, 2X2 mux-demuxers can be substituted for the 3dB couplers 30, 30', and in more complex arrangements 4X4, 8X8 or nxn mux-demuxers could be used with 4, 8 and n pairs of WDMs.

[0019] Fig. 5 illustrates yet another alternative embodiment wherein an arrayed waveguide grating multiplexer 50 (here 8x8) replaces the pair of MUX-DEMUX devices. The channels are mux-demuxed to port number 4 after being routed through the isolators. The advantage of this design is compactness.

Claims

1. An optical amplifier for a bi-directional WDM optical communications signal comprising:

   first and second bi-directional amplifier sections for amplifying multiple wavelength component signals passing therethrough in either direction; and

   disposed between said first and second amplifier stages a multiplexer section for separating signals from either one of said amplifiers into a plurality of wavelength components, passing them through unidirectional arms, and presenting the components in a recombined signal to the others of said amplifiers, whereby the effects of Rayleigh backscattering and amplified spontaneous emission are reduced.

2. The amplifier of claim 1 wherein at least one said unidirectional arm comprises an optical isolator.

3. The amplifier of claim 1 wherein at least one said unidirection arm comprises a circulator.

4. The amplifier of claim 1 wherein at least one said bi-directional amplifier section comprises a pair of optical circulators each having at least three ports, said circulators connected via a pair of optical amplifier arms.

5. The amplifier of claim 1 wherein said multiplexer comprises a pair of WDMs interconnected via optical paths containing isolators.

6. The amplifier of claim 5 wherein at least one said isolator is switchable or latchable.

7. The amplifier of claim 1 wherein said multiplexer

comprises a pair of WDMs interconnected via optical paths containing circulators.

8. The amplifier of claim 7 wherein at least one said circulator is switchable.

9. The amplifier of claim 1 wherein said multiplexer comprises an arrayed waveguide grating multiplexer.

10. The amplifier of claim 1 wherein at least one said bi-directional amplifier section comprises an optical circulator and a directional coupler.

FIG. 1

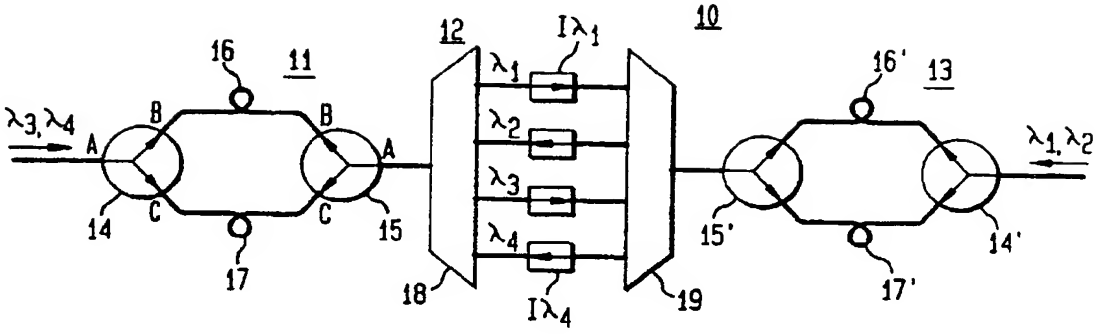


FIG. 2

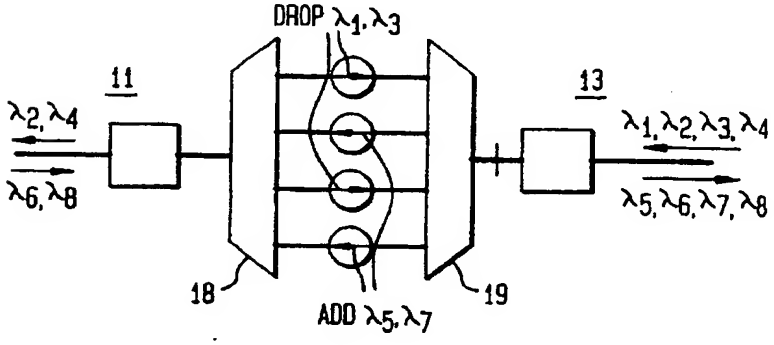


FIG. 3

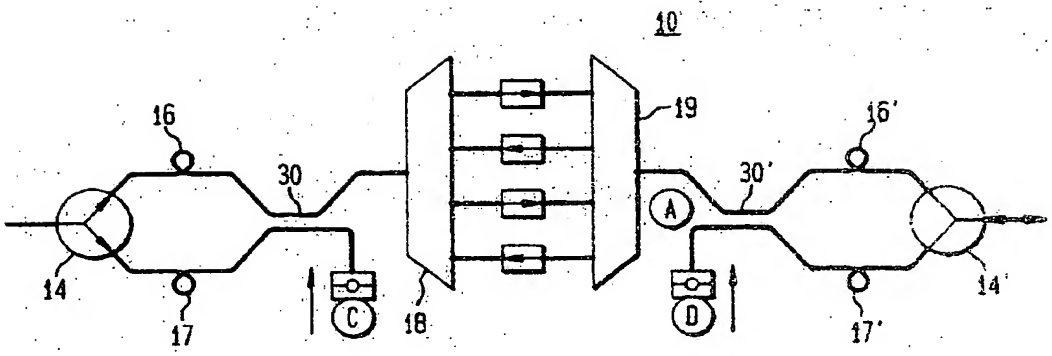


FIG. 4

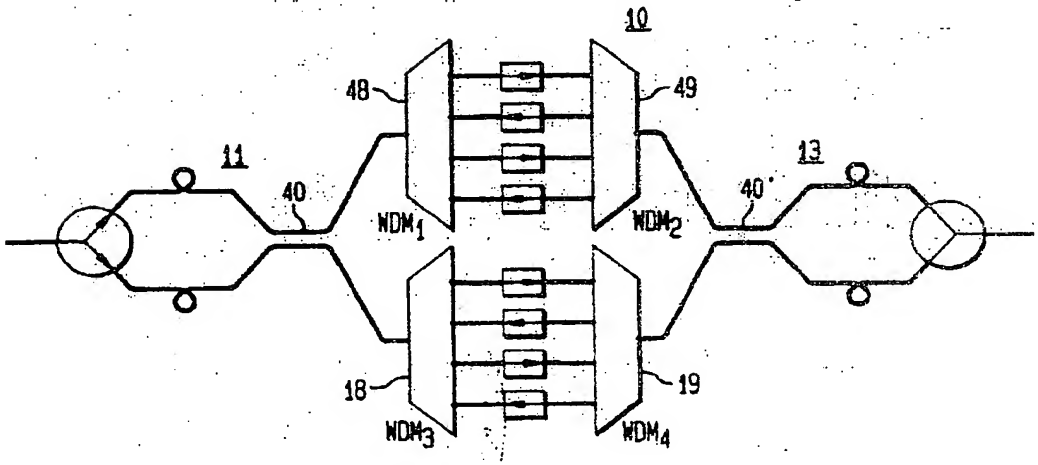
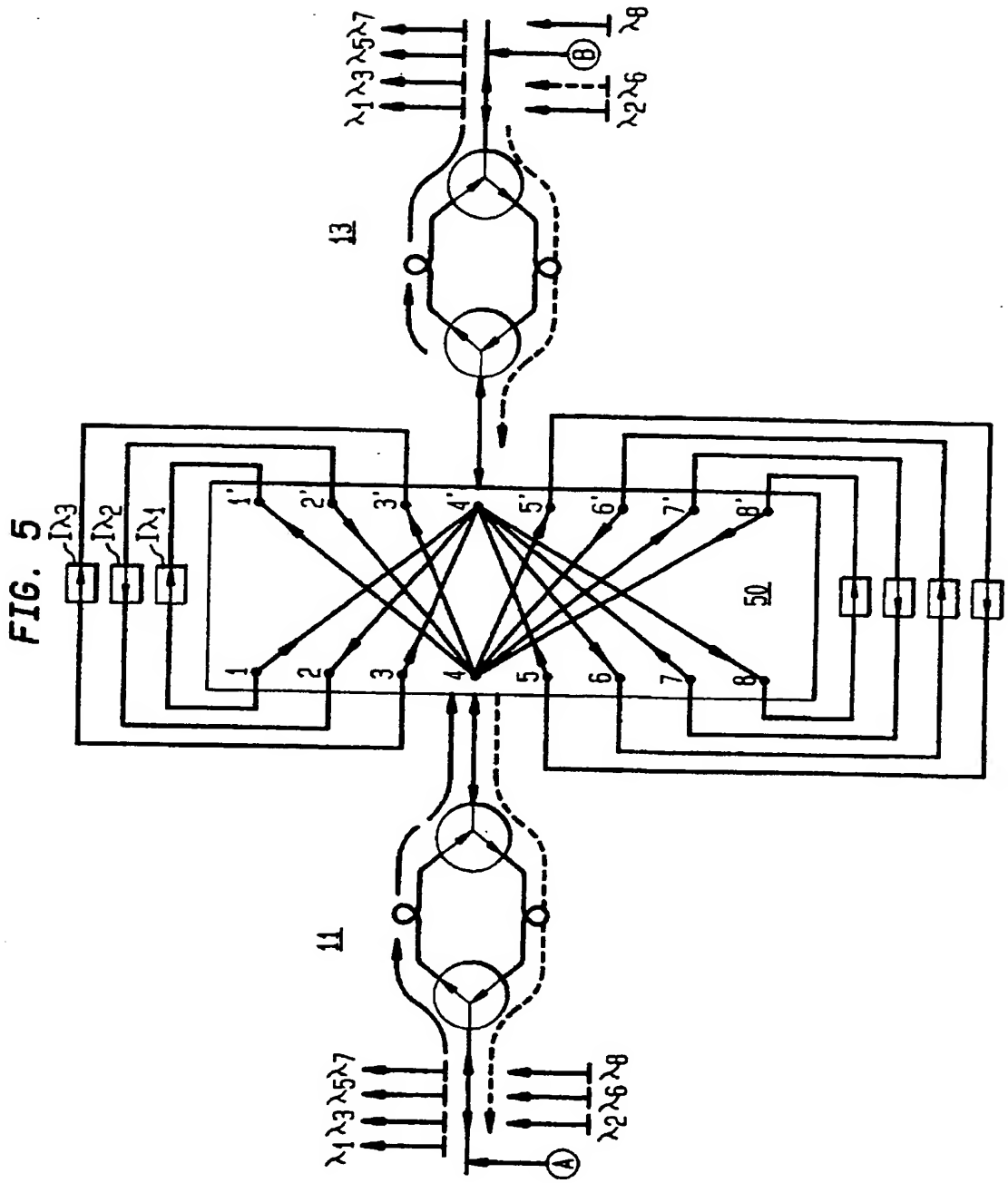


FIG. 5



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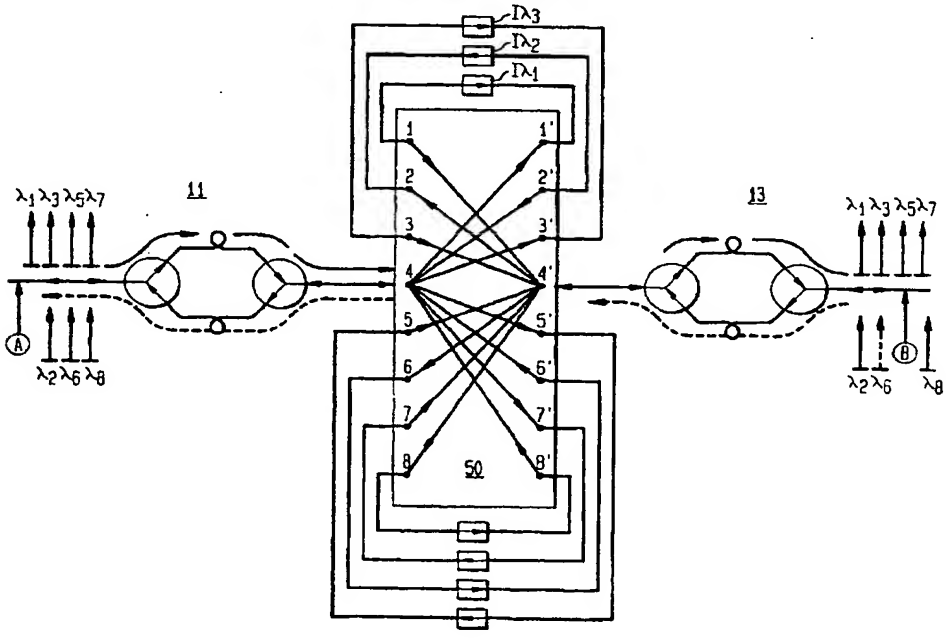

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EUROPEAN SEARCH REPORT

Application Number
EP 98 31 0188

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	LIAW S-K ET AL: "MULTICHANNEL BIDIRECTIONAL TRANSMISSION USING A WDM MUX/DMUX PAIR AND UNIDIRECTIONAL IN-LINE AMPLIFIERS" IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE INC. NEW YORK, US, vol. 9, no. 12, 1 December 1997 (1997-12-01), pages 1664-1666, XP000729132 ISSN: 1041-1135	1,2,5	H04B10/17 H04J14/02
A	* figures 1,2 *	6	
Y	BARNARD, CHROSTOWSKI, KAVEHRAD: "Bidirectional Fiber Amplifiers" IEEE PHOTONICS TECHNOLOGY, vol. 4, no. 8, August 1992 (1992-08), pages 911-913, XP001154817	1,2,5	
A	* figure 2 *		
Y	SHIGEYUKI SEIKAI ET AL: "EXPERIMENTAL STUDIES ON WAVELENGTH DIVISION BIDIRECTIONAL OPTICAL AMPLIFIERS USING AN ER3+-DOPED FIBER" JOURNAL OF LIGHTWAVE TECHNOLOGY, IEEE. NEW YORK, US, vol. 12, no. 5, 1 May 1994 (1994-05-01), pages 849-854, XP000480110 ISSN: 0733-8724	2,5	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H04B H04J H01S
A	* figure 1 *	6	
A	JP 05 233874 A (FUJITSU LTD) 10 September 1993 (1993-09-10) * abstract *	9	

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~~The present search report has been drawn up for all claims~~

Place of search	Date of completion of the search	Examiner
Munich	8 October 2003	Petitit, N

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 5 604 627 A (KOHN ULRICH) 18 February 1997 (1997-02-18) * figure 1 *	1,2,5,6, 9	
A	WO 95/15625 A (WILLIAMS TELECOMMUNICATIONS GR) 8 June 1995 (1995-06-08) * figure 8 *	1,2,5,6, 9	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

~~The present search report has been drawn up for all claims~~

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Munich	8 October 2003	Petitit, N

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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European Patent Office

Application Number
EP 98 31 0188

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1, 2, 5, 6, 9

European Patent Office

LACK OF UNITY OF INVENTION
SHEET B

Application Number
EP 98 31 0188

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1, 2, 5, 6, 9

   Bi-directional optical amplifier using a WDM multiplexer-demultiplexer stage with unidirectional arms on which isolators are placed to reduce amplified Rayleigh backscattering.

   ---

2. claims: 1, 3, 7, 8

   Bi-directional optical amplifier using a WDM multiplexer-demultiplexer stage with unidirectional arms on which are placed circulators to add and drop channels.

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3. claims: 1, 4, 10

   Two Bi-directional optical amplifiers and a WDM multiplexer-demultiplexer stage placed in-between. At least one bi-directional amplifier comprises a pair of circulators and a pair of optical amplifier arms.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 98 31 0188

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08-10-2003

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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WO 9515625 A	08-06-1995	AU 1296695 A WO 9515625 A1	19-06-1995 08-06-1995

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82